THE NEW MARS CLIMATE DATABASE (VERSION 4.2)

E. Millour(1), F. Forget(1), F. González-Galindo(1), A. Spiga(1), S.R. Lewis(2), L. Montabone(2), P.L. Read(3), M. A. López-Valverde(4), G. Gilli(4), J.-P. Huot(5), M.-C. Desjean(6) and the MCD/GCM development team

(1)Laboratoire de Météorologie Dynamique du CNRS, IPSL, Université Pierre & Marie Curie, BP99, 4 place Jussieu, 75252 Paris, Cedex 05, France, ehouarn.millour@lmd.jussieu.fr
(2)The Open University, Department of Physics & Astronomy, Walton Hall, Milton Keynes,MK7 6AA, United Kingdom
(3)Atmospheric, Oceanic & Planetary Physics, Clarendon Laboratory, Parks Road, Oxford, OX1 3PU, United Kingdom
(4)Instituto de Astrofísica de Andalucía, CSIC, Apdo 3004,18080 Granada, Spain
(5)ESA, Electromagnetics and Space Environment/TEC-EES, ESTEC, postbus 29, 2200 AG Noordwijk, Netherlands
(6)CNES, DSO/ED/MA,18 avenue Edouard Belin,31401 Toulouse, Cedex 4, France

ABSTRACT

The Mars Climate Database (MCD) is a database of meteorological statistics compiled from General Circulation Model (GCM) numerical simulations of the Martian atmosphere. The GCM has been developed over the years [1] at Laboratoire de Météorologie Dynamique (Paris, France) in collaboration with The Open University (Milton Keynes, UK), the Oxford University (Oxford, UK) and the Instituto de Astrofísica de Andalucía (Granada, Spain) with support from the Centre National d'Etudes Spaciales (CNES, France) and the European Space Agency (ESA).
The MCD has been validated using many sets of available observational data and is intended to be useful in the framework of engineering applications such as atmospheric trajectory computations as well as in the context of scientific studies. The MCD is freely distributed and may be accessed in two different forms: either (for moderate needs) via a WWW Live Access Server at http://www-mars.lmd.jussieu.fr or (for intensive and precise studies) via a DVD-ROM which contains all the necessary data files and post-processing software. Over the years, previous versions of the MCD [2,3] have been distributed to over a hundred teams around the world.
The new version of the MCD presented here includes all the features of its predecessors (with some improvements), and some additions such as a new "high resolution mode" and extra statistics on the altitude-wise standard deviations of main atmospheric variables.

1. OVERVIEW OF MCD CONTENTS

The Martian atmosphere is known to be highly variable. To represent the observed range of variability of the Martian atmosphere, known to be mainly determined by the distribution of dust in the atmosphere, the MCD accounts for 4 different dust scenarios.
The database extends up to ~350km and includes the thermosphere [4,5]. Since the influence of Extreme Ultra Violet (EUV) input from the Sun is significant in the latter, 3 EUV scenarios (minimum, average and maximum) are considered. Using these enables to account for the influence of the various states of the solar cycle on the Martian thermosphere.
The MCD provides mean values (and statistics on) the main meteorological variables (atmospheric temperature, density, pressure, winds and radiative fluxes) as well as atmospheric composition (including dust and water vapour and ice content), as the GCM from which the datasets are obtained includes both chemistry[6] and full water cycle[7] models.

2. RANGE OF VARIABILITIES REPRESENTED IN THE MCD

Because the variations (and variabilities) of meteorological variables occur over a wide range of scales, these are stored and accounted for as follows:
- Year to year variability due to the amount and distribution of suspended dust in the atmosphere; 4 dust scenarios are presented:
    - A baseline scenario, **MY24** (Mars Year 24), based on assimilation of TES observations[8] in 1999-2001.
    - Two scenarios which bracket average atmospheric conditions: a **cold** (clear sky) and **warm** (dusty) one.
    - A **global dust storm** scenario to represent conditions during such events.
- Year to year variability in the thermosphere (~100km and higher) resulting from the Extreme Ultra Violet (EUV) input due to the solar cycle. 3 EUV scenarios, minimum, average and maximum, are considered.
- Seasonal evolution is provided by the storage of 12 "typical" days (average over a Martian month which spans 30° in solar longitude) which are used to reconstruct values for a given date.
- Diurnal cycle: For each "typical" day, environmental data are stored at 12 times per day which are then used to reconstruct values at any time of day.
- Day to day variability: Aside from the mean values of meteorological variables mentioned above, the

variabilities thereof are extracted from the outputs of GCM runs and included in the MCD as follows:

- **Standard deviations** of main variables (surface pressure, surface temperature, dust opacity, atmospheric density, pressure, temperature and winds) are supplied.
- Users may reconstruct variabilities by adding perturbations to mean values; either in the form of **large scale perturbations**, using Empirical Orthogonal Functions (EOF) derived from GCM runs, or **small scale perturbations**, by adding gravity waves of user-defined wavelength.

3. NEW FEATURES SPECIFIC TO VERSION 4.2

The new version of the database includes all the features of its predecessor (seasonal interpolation, choice between multiple vertical coordinates, the possibility to specify input dates as Earth or Mars dates, etc…) along with two new features:

- RMS standard deviations of atmospheric variables are now given pressure-wise (as in previous versions of the MCD) and altitude-wise.
- A new "high resolution mode" has been implemented. It is achieved by combining MCD data (known at GCM horizontal resolution of 5.675°×3.75° in longitude×latitude) with high resolution (32 pixels/degree) MOLA topography and Viking Lander 1 pressure records (used as a reference to correct the atmospheric mass) to derive a high resolution surface pressure which is then used to reconstruct the vertical atmospheric pressure distribution and, within the restriction of the procedure, yield high resolution values of atmospheric variables. See Fig 1. for an illustration of low/high resolution outputs.

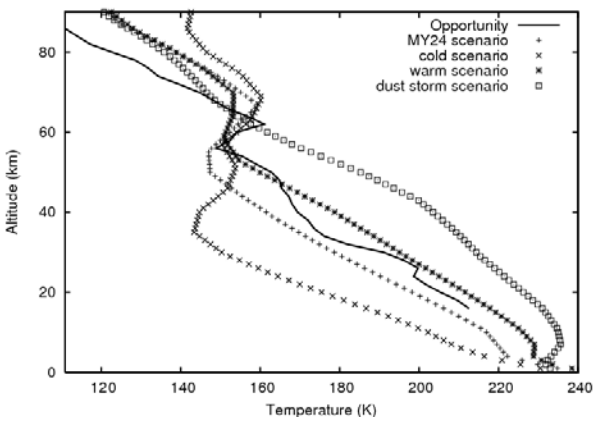

Fig. 2. Opportunity entry profile and MCD predictions

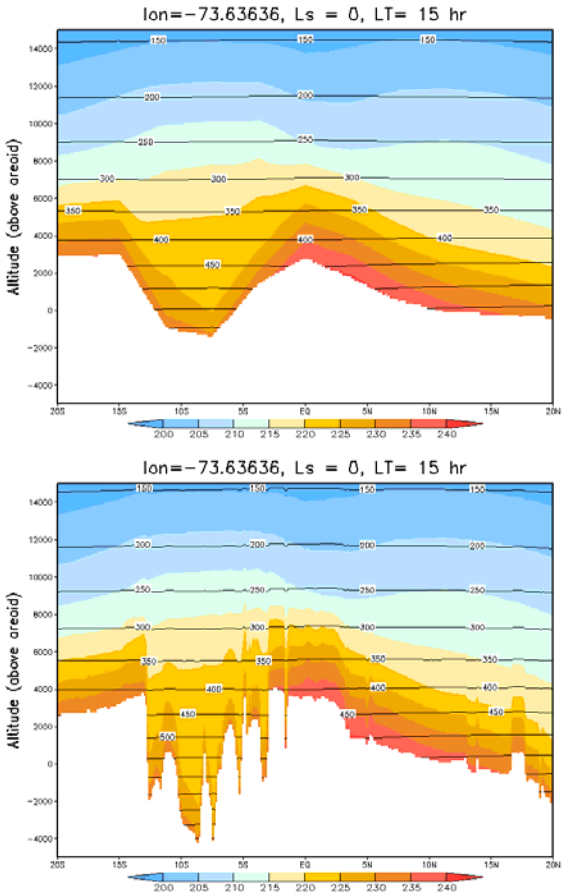

Fig. 1. Example of low/high resolution outputs: Sections of atmospheric temperature, in the early afternoon at Northern Hemisphere Spring equinox, above Valles Marineris, at low (top) and high (bottom) resolution. Note that there is an order of magnitude between horizontal and vertical scales in these plots; what appear as sharp spikes are in fact much smoother, as plots using commensurate axes would show.

4. VALIDITY OF MCD DATA

The MCD has been validated using many sets of available observational data, as illustrated by the following examples.

4.1 Example 1: Opportunity entry profile

Fig. 2 shows the temperature profile along Opportunity's entry, as retrieved by P. Withers[9], compared to MCD predictions using various dust scenarios. The measured temperature agrees well, both qualitatively and quantitatively with mean MCD profiles from the **MY24** baseline and **warm** scenarios, which correlates well with the known (from Mars Express and TES measurements) fact that the atmosphere was dustier than usual at the time of Opportunity's entry.

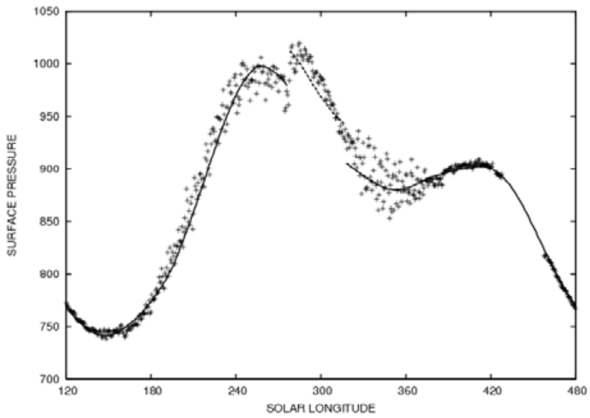

Fig. 3. Viking Lander 2 pressure vs. MCD predictions
This figure displays Viking Lander 2 (diurnally averaged) surface pressure records (crosses) over an entire Martian year along with MCD predictions using the baseline **MY24** scenario (solid line, for solar longitudes before Ls=275 and after Ls=315) and the **dust storm** scenario (dashed line, for solar longitude ranging from Ls=275 to Ls=315). By switching from one scenario to the other, the change in pressure due to the 1977 global dust storm that was recorded by Viking Lander 2 is recovered.

4.2 Example 2: Viking Lander pressure records

Both Viking Landers measured surface pressure over more than a Martian year, yielding very useful records depicting the seasonal evolution of the Martian atmosphere. These pressure records provide datasets to assess the quality of GCM outputs, as illustrated in Fig. 3, where the (diurnally averaged) surface pressure measured by Viking Lander 2 is compared to MCD predictions. This example illustrates the fact that the various dust scenarios provided by the MCD adequately mimic and restore atmospheric behaviour under standard (i.e. MY24-like) or more extreme (i.e. planet encircling dust storm) conditions.
Apart from being able to reproduce the mean atmospheric behaviour, it is also important to be able to yield correct values of the variability of atmospheric variables. As mentioned previously, the MCD contains the day to day variability (extracted from post-processing of GCM outputs) of many variables. These standard deviations give some insight on the amplitude of instantaneous deviations (compared to the mean values provided by the MCD) than one might expect to observe at a given location and time. An illustrative example is given in Fig. 4, where the mean surface pressure cycle over a Martian year predicted by the MCD is plotted, along with an envelope of twice its standard deviation and corresponding Viking Lander 2 records. The day to day variability observed in the measurements is clearly well represented in the MCD.

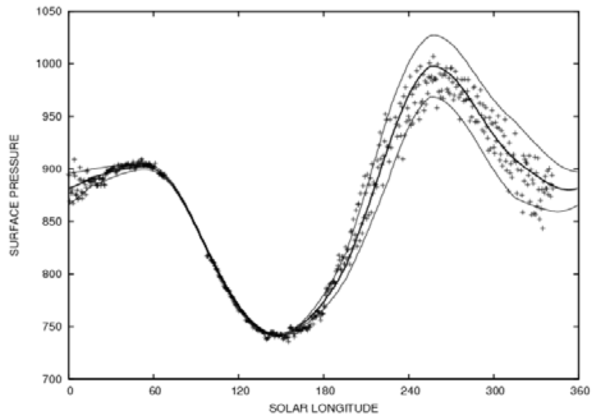

Fig. 4. Viking Lander 2 pressure vs. MCD predictions
Surface pressure cycle (heavy line) over a Martian year, as predicted by the baseline **MY24** scenario at the Viking Lander 2 site, with an envelope (thin line) of twice its standard deviations, compared to (diurnally averaged) Viking Lander 2 records (crosses).

4.3 Example 3: TES atmospheric temperatures

The Thermal Emission Spectrometer (TES) on-board Mars Global Surveyor (MGS) has almost continuously monitored the Martian atmosphere, yielding [10], among other quantities, numerous and detailed records of atmospheric temperature and its latitudinal, longitudinal and seasonal dependence.
This large data set is a good basis to evaluate the differences (and statistical spread) between MCD (mean) predictions and observations. As MGS is in a near polar solar-locked orbit, the spacecraft always views the same local times, 2am or 2pm (nominal values), and consequently data records are split between daytime and nighttime measurements.

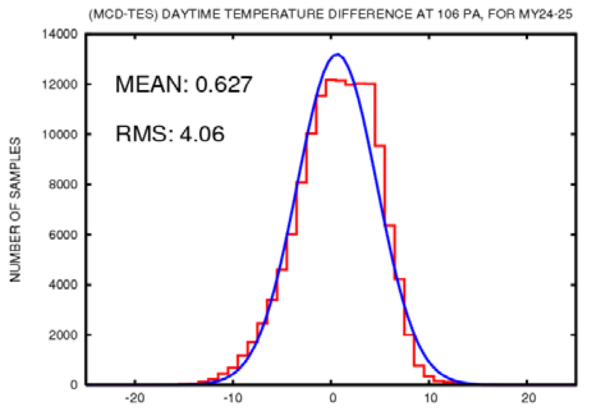

Fig. 5. MCD-TES data differences distribution
Distribution of binned (using 1K bins) 2pm temperature differences (at 106 Pa pressure level) between MCD predictions and TES measurements. Displayed MEAN and RMS values are computed from the obtained histogram. The curve corresponds to a normal distribution of same MEAN and RMS.

The distribution of differences between daytime atmospheric temperature at a 106 Pa pressure level is given in Fig. 5. All available data from TES, spanning Mars years 24 and 25 (up to Ls=180, i.e. before the global dust storm occurred) and in the latitudinal range of [-50;50], is compared to MCD predictions at same place and local time. The obtained statistical distribution gives a good impression of the accuracy of the MCD predictions (since the average difference between data sets is less than 1 K) as well as of the statistical spread between MCD values and actual events. Note that the shape of the obtained distribution is essentially that of a normal distribution.
The same statistical comparison, but for nighttime atmospheric temperature, yields similar insights, as shown in Fig. 6.

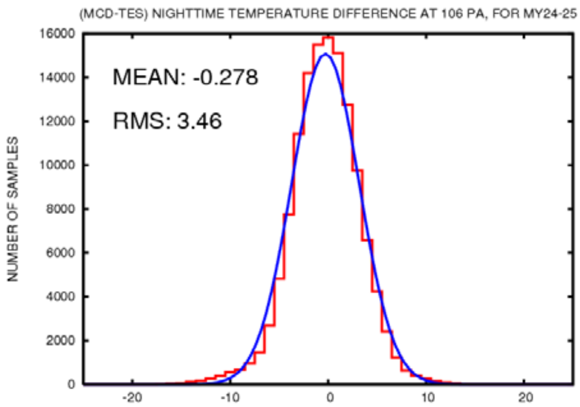

Fig. 6. MCD-TES data differences distribution
Distribution of binned (using 1K bins) 2pm temperature differences (at 106 Pa pressure level) between MCD predictions and TES measurements. Displayed MEAN and RMS values are computed from the obtained histogram. The curve corresponds to a normal distribution of same MEAN and RMS.

5. OBTAINING AND USING THE MCD

The Mars Climate Database is freely distributed and available in two different forms:
- *For moderate needs*: the Live Access Server World Wide Web interface (see Fig. 8) is available at http://www-mars.lmd.jussieu.fr and gives access to:

- All scenarios and main variables.
- A choice between 3 different vertical coordinates (pressure levels, altitude above areoid or above surface).
- A wide range of output formats: Images (gif or postscript files), NetCDF data files, various formats of text files.
- Computation of user-defined variables (averages, minimum or maximum values,…).
- An Earth date to Mars date (value of solar longitude Ls) converter.

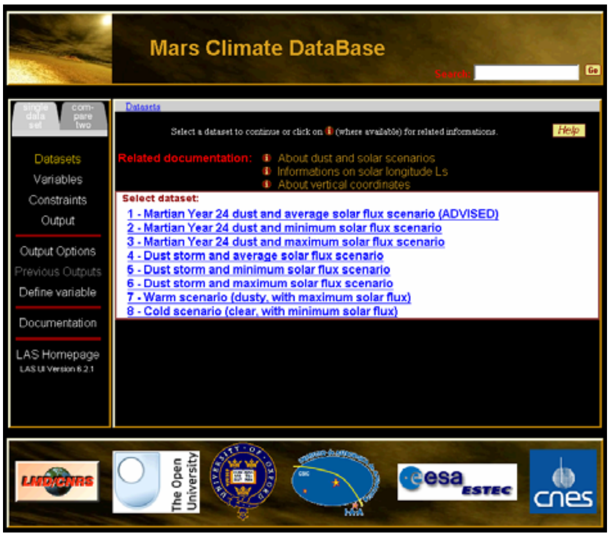

Fig. 7. Online version of the MCD
This Live Access Server, available at http://www-mars.lmd.jussieu.fr, can be used to retrieve MCD data.

- *For intensive and precise work*: The MCD is freely available and distributed as a DVD-ROM which contains:

- The data files (in NetCDF format).
- Access software (a Fortran 77 subroutine “call_mcd”) which does all the necessary post-processing to include and account for sub-grid scales, day to day variabilities, …). It has been developed on Unix systems but can be ported to Windows.
- Examples of IDL, Matlab, Scilab, C and C++ interfaces to the MCD.
- A lighter standalone high resolution surface pressure predictor “pres0”.

Just contact ehouarn.millour@lmd.jussieu.fr and/or francois.forget@lmd.jussieu.fr to obtain a free copy.

5.1 Detailed list of data provided in the MCD

The MCD provides the following variables:

- Atmospheric density, pressure, temperature and winds (horizontal and vertical),
- Surface pressure and temperature,
- CO_2 ice cover,
- Atmospheric turbulent kinetic energy,
- Thermal and solar radiative fluxes,
- Dust column opacity and mass mixing ratio,
- [H_2O] vapor and [H_2O] ice columns and mixing ratios
- [CO], [O], [O2], [N2], [CO2], [H2] and [O3] volume mixing ratios,
- Air specific heat capacity, viscosity and molecular gas constant R.

6. REFERENCES

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